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## 20 Years of Cluster Observations of Heavy Ion Outflow, Circulation in the Magnetosphere and Escape: Advances and Open Questions

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Outflow of ions from the terrestrial ionosphere and circulation in the magnetosphere plays an important role in the magnetospheric dynamics, by loading the magnetosphere with heavy atomic and molecular ions. Some of the outflowing ions can be re-injected into the inner magnetosphere, whereas some can completely escape to outer space. Cluster was the first mission in the magnetosphere to involve four spacecraft in a tetrahedral configuration, providing three-dimensional measurements of the space plasma parameters. The observations of the outflowing and escaping ion populations performed by Cluster are reviewed and the most prominent results highlighted. These show the dominance in the magnetotail lobes of cold plasma outflows originating from the polar caps. For the energetic heavy ion outflow the cusps constitute the main source. The dependence of the polar outflow on the solar wind parameters and on the geomagnetic activity has been evaluated for both cold ion populations and energetic heavy ions. For the later, outflow has been observed during all periods but an increase by two orders of magnitude has been shown during extreme space weather conditions. This outflow is adequate to change the composition of the atmosphere over geological time scales. At lower latitudes, the existence of a plasmaspheric wind, providing a continuous leak from plasmasphere, has been demonstrated. The general scheme of the outflowing ions circulation in the magnetosphere or escape, and its dependence on the IMF conditions, has been outlined. However, several questions remain open, waiting a future space mission to address them.